Ascendance, Resistance, Resilience

Concepts and Analyses for Designing Energy and Water Systems in a Changing Climate

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Certificate of Original Authorship

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Abstract

This thesis synthesises a set of improved concepts and analyses for designing energy and water systems in a changing climate.

The thesis begins by reviewing the concepts that have influenced the planning, design and assessment of energy and water systems through time. The conceptual development is characterised as a series of emerging paradigms or 'waves', each providing new insights while revealing new conceptual blind spots. The review finds a series of conceptual ambiguities and tensions that may be inhibiting a more integrated perspective. Based on the premise that cities may be better characterised as coupled ecological and economic systems, the review then explores several fields seeking an interdisciplinary synthesis between ecology and economics, and finds much has been 'lost in translation' as the concepts have been adapted and operationalised.

The thesis then embarks on a broad and deep historical literature review to identify the concepts observed to underlie systemic performance in ecology and economics. In so doing, a conceptual framework is synthesised to provide a coherent model for systemic performance drawn from both disciplines. The framework comprises three attributes: the capacity of a system to thrive despite resource scarcity and competition, termed 'ascendance'; the capacity of a system to absorb variability, fluctuation and disturbance and remain essentially unchanged, termed 'resistance'; and the capacity of a system to adapt with shocks, shifts and perturbation and avoid systemic failure, termed 'resilience'. Each attribute is addressed in turn by first identifying the underlying drivers or imperatives (the 'why'), then by elaborating its various definitions within the literature (the 'what'), and then by unpacking the underlying mechanisms toward its development (the 'how').

Returning to the fields of urban water and energy planning, the thesis then explores the extent to which the conceptual framework translates and provides new insights into urban water and energy systems. The translation demonstrates a clear alignment between the conceptual findings of ecology and economics and emerging patterns in urban water and energy systems. Furthermore, the translation reveals how the conceptual framework may be applied to describe, analyse and design for improved systemic performance.

The thesis then analyses a set of candidate analytical methods for assessing each attribute of the conceptual framework, including the strengths, limitations and appropriate role of each

analytical method. A set of heuristics is then developed for structuring an integrated assessment of systemic performance.

The thesis then demonstrates and validates the identified concepts and analyses by elaborating a set of hypothetical case studies supplemented by analytical modelling. The case studies provide a practical demonstration of how the concepts and analyses may be applied in a set of realistic problem situations. They further demonstrate how the concepts and analyses result in improved outcomes, both in cost-effectiveness and robustness.

A discussion of the key findings and contributions of the research follows, together with some concluding remarks regarding the research limitations and future research opportunities.

Foreword

The stimulus for this thesis was my work as a consulting researcher and policy analyst at the UTS Institute for Sustainable Futures. During my time in this role, the organisations that we worked with were grappling with a set of challenges: electricity utilities were struggling to meet their reliability standards in the face of escalating peak demand; water utilities were struggling to maintain water security in the face of a series of severe droughts experienced across Australia; and government agencies were attempting to form policies to simultaneously mitigate and adapt with the emerging reality of a changing climate.

My specific professional focus was on applying and extending 'integrated resource planning'– a system modelling, forecasting and strategic assessment approach predominantly applied in the energy and water sectors. A point of differentiation of this approach is its ability to compare a much wider range of interventions, including 'supply-side options' such as network augmentations, reservoirs and new generators, and 'demand side options' including end-use efficiency, recycling and source substitution.

However, we were increasingly finding that the concepts and analyses underpinning the approach were no longer sufficient for the challenges that we were dealing with. Faced with unprecedented demand uncertainty, electricity utilities were dramatically augmenting network capacities, leading to unprecedented rises in electricity prices. Meanwhile, water utilities across the country were resorting to the construction of a series of expensive desalination plants. In both cases the key justification for the investment was that they provided the necessary 'insurance' to maintain acceptable levels of reliability and security. Many at our institute suspected there must be a smarter way forward but the alternative responses, including embedded storage, renewable generation, and decentralised water systems, were difficult to model and assess using existing conceptual and analytical frameworks.

I suspected that economic and ecological theory might offer a more nuanced way of grappling with these challenges owing to their much deeper empirical experience with complex and adaptive systems. I therefore decided to commence a transdisciplinary PhD at the Institute for Sustainable Futures to test that theory – a journey that took me two hundred years back in time, around the world and back again, only to leave me with more questions. This thesis is the best I could do to describe what I found.